Emerging From Engineering Education
– Building a Remotely Operated Submarine

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Abstract

In spring 2004, the Department of Mechanical Engineering of Rowan University offered a new course called "Emerging Topic – Designing and Building a Remotely Operated Vehicle (ROV)". It is a project-based course where students are required to design, build and operate a submersible with provided materials. This course integrated many engineering aspects into one project and also exposed mechanical engineering students to Mechatronics. The course was welcomed by students and the response from them was quite positive.

1. Introduction

Established in 1994, the College of Engineering at Rowan University is known for its hallmark of hands-on education from its first day. The unique Engineering Clinic series leads the way of hands-on minds-on education, while many traditionally theoretical courses also introduced various projects to bring more hands-on flavor. Following this tradition, many new courses were also proposed and introduced with heavy emphasis on projects and hands-on experience. In the spring 2004, the department of Mechanical Engineering of Rowan University developed a new breed of senior course, which is currently named "Emerging Topic – Designing and Building a Remotely Operated Vehicle (ROV)". It is a project-based course where students are required to design, build and operate a submersible with provided materials. At the end of the semester, the finished ROVs competed in a series of underwater events in the Rowan swimming pool and also performed a field exploration in a local pond.

In recent years, robots and various kinds of ROVs are becoming increasingly popular in scientific research, education and public entertainment. To many people, they have become almost the hallmark of modern engineering and technology, especially the "real" tangible part of the field. Among the various ROVs, we chose the underwater ROV to be the subject of our new hands-on project based course since its skill level is proper for undergraduate education and its operation is manageable within the scope of a regular course.

The course proved to be successful. It not only provided a memorable experience for the students during their final semester, but also helped the seniors to refresh and apply the knowledge they learned during the past years. This course also exposed Mechanical

Engineering students to mechatronic systems, and prepared them for the current trend of converging mechanical engineering with electrical engineering.

The layout of this paper is as follows. After this introduction, we will give more reasons and benefits of introducing underwater ROV into curriculum in Section 2. Then we will give detailed descriptions of the course and the final competition in Section 3 and 4 respectively. The paper will be concluded with a brief summary in Section 5.

2. Why underwater Remotely Operated Vehicle?

During the last semester of their college life, it is often a challenge for the seniors to keep concentrated in classes, especially under the distraction of job hunting and offering, graduate school application and preparation, and endless farewell parties. Though it does not mean that no courses should be offered then, it will be practical to offer more project-based hands-on courses and the courses that emphasize more on integrating and practicing existing knowledge instead of entirely new content. In many schools, capstone design is often a satisfying answer. In Rowan University, there are already many hands-on project-based credits available from the unique Engineering Clinics offered throughout the four years. However, the projects in Junior/Senior Engineering Clinics are often based on faculty research or external industrial projects, which are naturally distinctive from each other. We feel that it will be helpful if we can provide a touchstone project that will put all the students on a common ground. In this course, the core curricula of Mechanical Engineering, such as Machine Design, Mechanical Design, and Fluid Dynamics will be combined and be put into test on a real design problem. The seniors will have an opportunity to examine and apply their knowledge effectively.

At the same time, electrical and computer engineering is rapidly converging with mechanical engineering. Mechatronics, or electro-mechanical engineering, an interdisciplinary filed, is growing quickly. Meanwhile, microprocessors and other electrical components also find their ways to traditional mechanical systems for "smart" machines. On the other hand, this trend of embedding electrical and computer components into mechanical engineering also posts a new challenge to the education of Mechanical Engineering today. That is, to many traditional or "pure" mechanical engineering students, any electrical component, or even a piece of electric wire is considered a mystery in an unknown territory. Although all the students are required to take courses like Networks and Electronics, many managed to reset themselves quickly. One strategy of Rowan Mechanical Engineering is to keep exposing the students with the subjects by integrating them into the curriculum and keep refreshing their memories with topics that are interested to them. We have developed or modified several courses under this strategy, such as the introduction of a new course Mechatronics and implementation of many hands-on projects (called Junior/Senior Engineering Clinics) co-sponsored by the department of Electrical and Computer Engineering. Among these practices, one successful approach is to build remotely controlled submarines.

Furthermore, from years of experience, we learned that to understand automobiles better is often a driving force for many Mechanical Engineering freshmen in Rowan University. Although they quickly learned that mechanical engineering is far more than just automotive technology, many of them still keep the dream of building a super car and enjoy the hobby of repairing and remodelling their vehicles. There is also a strong and active SAE student chapter in Rowan Engineering, which is participating in the Mini-Baja competition[2] every year. It will be beneficial if we could steer the student interest toward a more productive direction. Meanwhile, there is a relatively strong Robotics Lab in Mechanical Engineering. A series of courses[6] and student projects[4] have developed with the focus on robots. Moreover, in the summer 2003, two faculty members participated in the Marine Advanced Technology Education (MATE)[3] workshop sponsored by Monterey Peninsula College. When these elements were put together, the idea was inspired and we decided to use underwater ROVs as the tool to immerse the mechanical engineering students with mechatronic projects, while putting their knowledge learned in the past years into a serious test.

Compared to the other kinds of ROVs, such as an R/C car, a mini robot, or a model airplane, the underwater ROVs, or remotely controlled submarines are better suited for our educational goals since:

1. It is a typical and non-trivial mechatronic system that requires hands-on capability on both mechanical and electrical design and fabrication. The process of design, development and fabrication requires a solid background and proficient skills in corresponding areas.

2. It is more challenging than land-based ROVs. An underwater ROV needs to travel in 3 independent directions, i.e., forward/backward, left/right, and up/down. To keep it neutrally buoyant is also not an easy task, especially when there is a change of payload after picking up underwater objects. Further, keeping the electric component dry in water and under pressure is a tremendously difficult problem. Indeed, three cameras were flooded among the total ten teams. The majority are successful at sealing, though.

3. It is more controllable than an airborne vehicle since the speed of a submarine is relatively slow, the buoyancy is easier to obtain in water, and the operating zone (testing water tank or a swimming pool) is readily defined. Meanwhile, the test of flight is often subject to the inclement weather, while the indoor environment is controllable and there are more possible and safe test drives for underwater ROV.

4. It is scalable for large or small projects. The different functions of an ROV can be decoupled and different levels of assemblies can be provided. For example, we can require a full version with remote controller, on-board camera, end-effector and active buoyancy control for senior undergraduate students. They also need to design, machine and assemble their body structures and thrusters. On the other hand, if we supply pre-cut PVC pipes and pre-assembled thrusters and remote controller, a stripped-down version will be suitable for high school students in a 2~3 week summer camp.

5. It is more rewarding, or perceived more rewarding to students due to the fact that it is generally a mysterious world underwater, even just a meter deep because we can not see clearly through the water, though we can send our eyesight high. It is also delightful to see that the students put the ROV into exploring a pond near campus and invited faculty members to take a look at the bottom of it. The course even inspired a new research

project with the Department of Biology to build an ROV and to survey the current pollution level in local ponds.

6. It exposed our students to many marine related job opportunities. There are many demanding but high paying positions in areas such as marine transportation, fishing and other similar areas. Although there was no direct job placement resulted from building model submarines this time, it does open a door for our students to a whole new world of possibility.

3. Format of the course

The course was divided into two parts. One is the theoretical study while the other is the hands-on fabrication. On the theoretical part, we want it to be a course that can integrate most if not all the knowledge they learned in the past few years. That is, it can be a version similar to the regular capstone design project. At the bottom line, the students need to study the buoyancy control, calculate power and weight distribution, design pick-up tools and remote control box, streamline the body, and find ways to keep pressured water from flooding into the camera compartment. Although a textbook[1] is available and used for lectures, the students need to dive deeper. Every team is assigned a research topic related to underwater technologies as their focus of research during the semester.

For example, one difficulty faced by underwater vehicles, both manned and unmanned, is underwater localization and underwater communication. Though it is relatively easy now to use various tools (such as sun and star, GPS, and radio) to find the position and orientation of oneself and communicate with other people on land, it is a huge challenge to do the same thing since light and other radio waves can not travel far in water. Current technologies utilize sonar and umbilical, but the former is slow and carries very narrow bandwidth while the latter is limited in range and brings huge drag resistance in deep sea operation. Even in a regular indoor swimming pool and with a short umbilical (10 meters), there is a non-trivial problem of localization and communication, especially when the ROV is traveling outside the direct eyesight and the operator can only “feel” the vehicle through the onboard camera. From this personal experience, the students got a glimpse of the real challenge in the pitch dark of the deep sea, which also fascinated them to search for solutions.

The research topics drew upon many R&D resources and sprang many novel approaches in industry. For our students, they need to fully understand the problems, search the Internet and library to find the most recent development in the areas, and then write peer reviewed (by their classmates) technical papers to summarize their findings and propose their own ideas of improvement. Each team is also required to give a 15 minute oral presentation with visual aid to the entire class, explain the topic and their findings and answer any question within their ability. Through this procedure of extending from exploration to explanation, each student group grows a deep understanding of the specific topic they were asked to study, while the entire class could learn the knowledge on the full spectrum of the topics, from high speed underwater propulsion, sealing under high pressure, to new pressure resistant materials.

The hands-on part of the course is to design, build and drive a functional mini-underwater ROV. The budget is about $120 per team, plus any scrap in the machine shop. Within the budget, the department will provide one mini-camera ($33), three bilge pumps ($36) and three propellers ($11.5) for thrusters, certain amount of PVC pipes, glues and cements. Each team was also provided with some potentiometers, transistors, switches, wire, and other electrical part to make the remote controller. Although some students were willing to spend a fortune to make a killer ROV for bragging rights, we only permitted $20 out of pocket allowance per team to buy their own parts, and the receipt should be brought to the final presentation for public scrutiny. This allowed the competition to be held on a leveled playing field, so the students with deep pockets will not have an advantage.

At senior level, the students should have the necessary knowledge for a formal approach of an engineering design. Therefore, we required them to first give a conceptual sketch and basic calculations of buoyancy and power, and then use SolidWorks, a version of 3D engineering drawing software, to draw the detail of every component and to provide guidance for final assembly. Figure 1 shows the proposed design of a ROV and the final product of the design at the end of the semester.

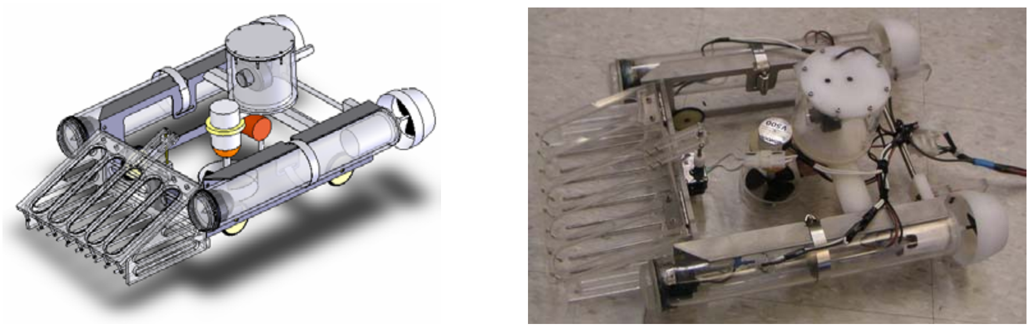

Figure 1: One proposed ROV rendered by SolidWorks (left) and its corresponding final product (right).

The fabrication and machining of the ROVs took about one third of the total class time. We realized that if we just turn the students loose and ask them to show up with their products before the competition, the time can not be enough, no matter how much it is given. We planned two tactics to attack the problem. First, we interlace the machining time with the theoretical study; hence stretch the starting date to the early half of the semester. For the students with a solid idea, they can start early and spend more time to test drive and improve. For those need extra time to finalize, they can put more machining time toward the end. By doing this, we can also spread the usage of the machining tools more evenly. There are ten teams, but only 3 milling machines and a handful of hand tools. The waiting will be intolerable if all the students are competing for the machine time.

The second tool to control the schedule is to employ the progress report. At the beginning of the semester, we asked the students to divide their work into several manageable parts. They need to make plans, stick to them, and submit a progress report each week to document their advancement. Since the progress reports are counted toward the final grade, they provide a motivation to work on their project early during the semester.

On the other hand, for this kind of semester-long project, there will be always last minute crunches. As expected, there were several sleepless nights before the competition, and the machine shop were heavily crowded with the students for the last week. However, all teams managed to finish their submarines before the contest time and participated in the competition. Figure 2 shows a happy and proud team with their ROV. They won the beauty contest of the ROVs.

Figure 2: One happy team with their ROV.

4. Competition

The climax of the course is the final competition on April 23rd, 2004, when the various designs and secret tricks were all revealed and challenged. The arena of the competition is the Esby swimming pool of the Student Recreation Center of Rowan University. The ROV competition includes four events, with different weights assigned to each one. The overall final score of the competition is calculated as

$$\text{Final Score} = \sum_i (21 - R_i) \cdot W_i$$

where W_i and R_i are weight and rank of each component of the competition respectively. Since there are 10 teams, R_i will range from 11 to 21 to show the work done for the unfinished projects. The four events are:

1. Underwater maze (W_1=0.6). As shown in Figure 3, an underwater tunnel (10’x4’x4’) is laid on the bottom of the swimming pool. The top of the tunnel is covered while there are several internal diagonal wires to block the straight path. ROVs should enter from one end of the maze, travel through the tunnel by swimming around the wires, emerge at the other end, and then return to the entrance through the maze again.

2. PVC mining (W_2=0.6). As illustrated in Figure 4, ROVs need to pick up various objects from a 4’x4’ mining zone, and then dump them to a 3’x3’ dumping area 10 feet away. The ROV can run back and forth as many times as necessary in 5 minutes,

Different shapes of objects carry different points, while a smaller bull's eye area in dumping zone will double the point.

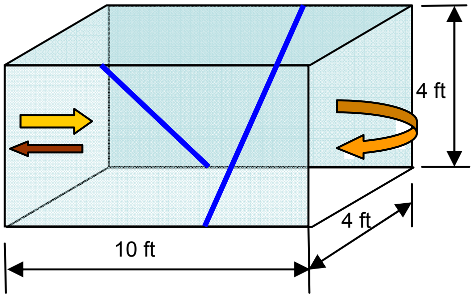

Figure 3: Illustration of underwater maze.

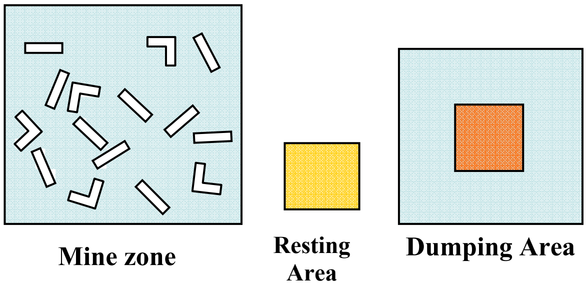

Figure 4: Illustration of underwater mining.

3. Sprint relay (W_3=0.4). In the sprint relay, ROVs needs to swim back and forth for 20 feet. As shown in Figure 5, all ROVs start from one side of the swimming pool, which is the starting line. They need to pass the returning line, and then either turn back, or just drive backward to return to the starting line. To promote the participation of all students, every member of each team needs to drive the ROV at least one lap in this contest. Then the average time for one lap will be counted toward the final grade.

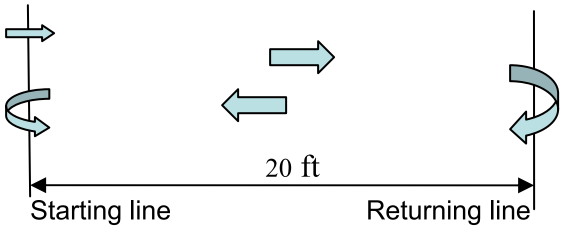

Figure 5: Illustration of sprint relay.

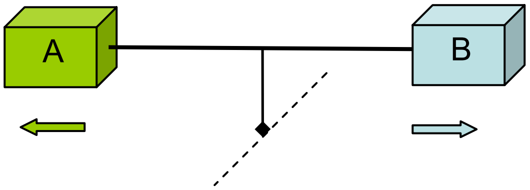

Figure 6: Illustration of tug of war.

4. Tug of war (W_4=0.4). In the Tug of war, ROVs were paired to compete with each other as shown in Figure 6. In each match, the ROV that could drag the opponent toward its end of the pool for one foot wins.

The following figures show two snapshots of the competition. In Figure 7, one student group is controlling their ROV for the Underwater Maze contest. In the left image, an operator is using a hand controller to control the direction and speed of the ROV, while using a TV set to display the video stream fed from the onboard camera. Because the top of the underwater maze is covered, the only feedback he can get is from the TV screen. At the same time, his teammates are trying to obtain any clue of their ROVs position by peeking into the water or simply guessing. On the right image, the ROV under control is making its way into the maze. It is generally a major task to keep the ROV swimming straight if the left and right thrusters are independently controlled and no automatic compensation device is used. The drag from the tether is also increasing the difficulty of the event.

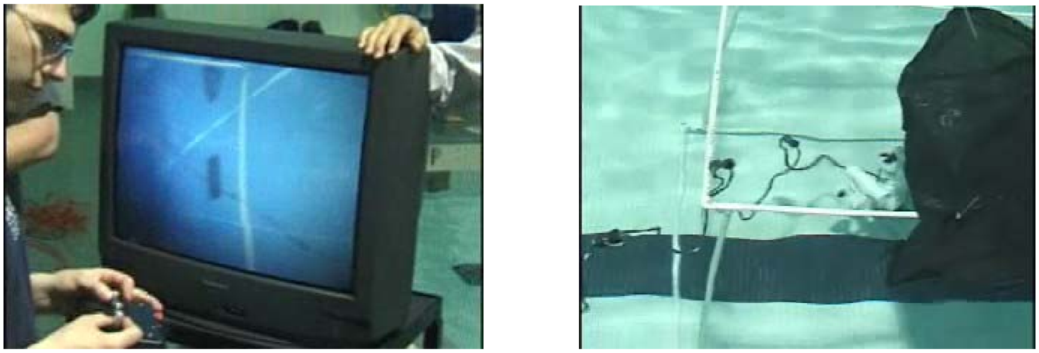

Figure 7: In Underwater Maze, a student is remotely controlling his ROV (left) to enter the maze (right).

In Figure 8, one ROV is controlled to compete in Underwater Mining. Though it is possible to control the ROV by looking at it directly from pool side, it is sometime easier to view the target from underwater. The water deflection often makes it harder to pinpoint the object to be picked up. Students quickly figured out that the best strategy is to combine the information from the onboard camera and the pool side observer together. The former can help pick up the individual object, while the latter give an overall sense of position and orientation. They learned and acknowledged that a real ROV working in the deep sea environment will only give them local feedback, but it makes sense to treat their own problem with any tool in hand. Another major challenge to the students is to keep neutrally buoyant after picking up the objects. For those without active control of buoyancy, it works better to run back and forth more often with fewer objects on board.

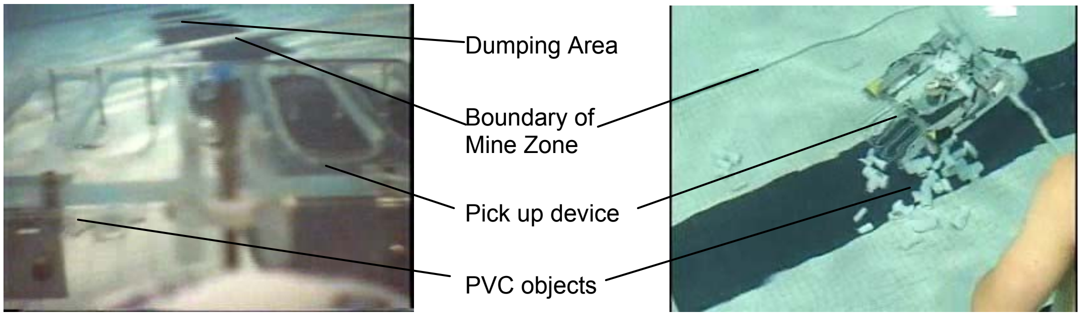

Figure 8: On-board (left) and external (right) views of an ROV in Underwater Mining.

5. Discussion

The introduction of ROV technology to engineering education proves to be a success. This mechatronic project integrates the topic of Machine Design, Mechanical Design, Electronics, and Fluid Dynamics into one senior-level course. It also introduces the students to new science and engineering frontiers such as Marine Technology, Robotics, and Ocean Ecology. It emphasizes hands-on experience, and promotes teamwork within and among groups. Since the project is also contest oriented, teams work to maximize the introduction of creative ideas into their designs. Creativity is further encouraged by providing a limited supply of material and the awarding of extra credit if a team's idea is shared and adopted by other groups.

Besides hands-on design, construction, and operation, the project also requires students to attend lectures and to do research on the history and technology of remotely operated underwater vehicles, from material to drag reduction and from navigation to control. They are also required to write papers, prepare progress reports, and give several presentations based on their research and design.

Designing and building ROVs greatly stimulated the interests and the creativity of the students. In fact, some students have become so inspired by this project that they have begun to take SCUBA diving classes. The success of the course also inspired ME faculty to offer an abbreviated workshop in the summer as an outreach activity to high school students to inspire stronger interest in engineering[5].

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Biographical Information

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JOHN CHEN is an Associate Professor of Mechanical Engineering. He has been a faculty member since 1994, when he began his career as an Assistant Professor in the Department of Mechanical Engineering at North Carolina A&T State University. He joined Rowan University in his current position in 1998.